Journal of Forestry Research (2011) 22(1): 65−70
DOI 10.1007/s11676-011-0127-2

ORIGINAL PAPER

Assessment of the effects of the shelterbelt on the soil temperature at regional scale based on MODIS data

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Received: 2010-04-16; Accepted: 2010-07-20

Abstract: At present, the most researches on the protected effect of shelterbelt are on the basis of the two scales of forest belts and networks. However, with the further research on the global environmental change, more attention was paid to the regional climate effect of shelterbelt. In present study, we analyzed the temperature effect of the shelterbelt at regional scale by using the land surface temperature (LST) data from the moderate resolution imaging spectroradiometer (MODIS) at Yushu, Nong'an, Dehui, and Fuyu in Jilin Province of China from March to October in 2008. Results show that the shelterbelt can increase the soil temperature of the protected farmland as compared with no shelterbelt zone, with the increment of 0.57ºC per day in fine shelterbelt and 0.38ºC per day in the normal shelterbelt. Moreover, the correlation analysis of the air temperature, precipitation and the soil type and the shelterbelt effect shows that the air temperature and precipitation are negatively correlated with the shelterbelt effects, that is, the more the temperature and precipitation are, the less the effect produced. While the impact of the soil types on the shelterbelt's effect is not very obvious as a whole. This paper draws significance in terms of analyzing the effects of the shelterbelt on the soil temperature at regional scale utilizing the remotely sensed data and GIS technique.

Foundation project: This work is supported by the Knowledge Innovation Program of the Chinese Academy Sciences (No. KZCX1-YW-08-02-01) and National High-tech Research and development Program of China (No. 2006AA10Z227).

The online version is available at http://www.springerlink.com

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Responsible editor: Hu Yanbo

Keywords: regional scale; remote sensing; shelterbelt; temperature effect

Introduction

With the rapid growth of population, there is an increasing demand for food. This caused extensive deforestation, the excess utilization of land, and consequently serious ecological problems, including desertification, soil and water loss, flood disaster, species extinction and increase in green house effect, etc., which in turn caused great damages to production and living condition of human. How to develop a mode of production, which could not only guarantee the crop yield, but also sustain the ecological stabilization, is a question people are thinking about.

Under this background, agroforestry is receiving long overdue attention as an alternative land-use practice that is resource efficient and environmentally friendly (Jose and Gordon 2008). Agroforestry, the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land, has been an established practice for centuries (Alavalapati et al. 2004). In the late 1970s, agroforestry attracted the attention of the international scientific and development communities due to its potential for improving the environment and livelihood of rural tropical communities. The agroforestry prospective increased further during the 1990s as scientists and policymakers recognized the potential for applying agroforestry systems (AFS) to solve problems in temperate zones and develop economies. Financial viability and attractiveness has also proven AFS an important land use alternative in various settings throughout the world (Garrett 1997), generating increased interest in this sustainable land-use management practice with potential environmental and socioeconomic benefits.

Based on the purposes, the agroforestry practices can be divided into many types, and the shelterbelt is one type of them. Windbreaks or shelterbelts are barriers used to reduce wind speed. Throughout history they have been used to protect homes, crops and livestock, control wind erosion and blowing snow, provide habitat for wildlife, and enhance the agricultural landscape (Brandle et al. 2004).

The purpose of the shelterbelt construction is to improve the environment, protect the farmland, and increase the crop yield. Many researches have been conducted on the ecological effect of the shelterbelt. The direct effect of the shelterbelt is reduction of the wind speed. Cleugh et al. (1998) described those mechanisms by which wind directly affects crop growth rates and hence yields. Cleugh (1998) addressed the mechanisms by which a porous windbreak modifies airflow, microclimates and hence crop yields, based upon recent wind tunnel experiments, field observations and numerical modeling. Nelmes et al. (2001) used the method of combination of field and wind tunnel measurements to determine the protective effect of shelterbelt. Mulati and Norio (2009) used the similar method and found that the windbreak width greatly affects the location and the magnitude of the minimum wind velocity. The shelterbelts reduced the wind speed, further changed the temperature and moisture in the network, and influenced the ambient environment. Therefore, many researches focused on the effects of shelterbelts on temperature or moisture. For example, McNaughton (1988) indicated that average soil temperatures in shelterbelts are slightly warmer than in the unprotected areas by field measurement; Wang et al. (2008) measured the temperature and humidity of the shelterbelt micro-climate on both horizontal and vertical scales in the extremely drought area to investigate the effects of shelterbelt; Campi et al. (2009) used wind speed, evapotranspiration, crop yield etc. to analyze the protective effect.

The past researches are mainly based on the field observation, with the small spatial scale, generally at shelterbelt's belt or network scale, and the limited data only from a single day. Because of these restrictions, we can not obtain the data in synchronism, and hardly reveal the law at regional scale. Furthermore, the ecological significance is not only confined to one belt or network, but also to the regional scale. With the further study of the global environment, the impact of the shelterbelt on regional climate will become the hot spot in this field (Fan et al. 2002). Hence we need to perform the regional study with the aid of new methods.

Satellite-based remote sensing cannot currently provide atmospheric information at a small scale, but it is useful in describing the climate patterns by recording surface temperatures, soil moisture, land cover, and vegetation density, etc. (Netzband et al. 2007). Remote sensing can provide periodically updated land-use and land-cover data useful for local climate prediction. In the present research, we considered the 8-days composite MODIS LST data at 1 km spatial resolution and analyzed the change of soil temperature at regional scale. The objectives of the present research were to (1) analyze the temperature effect of the shelterbelt at regional scale and the temperature effect of the shelterbelt on long-term basis, and (2) provide a new method for the shelterbelt's effect research.

Material and methods

Site description

The study area is located in midwestern Jilin Province of China. It covers Yushu, Nong'an, Dehui and Fuyu between longitude 124°23′27″ to 127°13′13″ E and latitude 43°41′42″ to 45°32′54″ N (Fig. 1). The terrain is flat and the agricultural land is used mainly for corn production and has a wide variety of planted shelterbelts, which is a part of the Shelter Forest System Program in three North Regions of China.

Fig. 1 The location of the study area

Data acquisition and processing of Shelterbelt and land use data

In order to guarantee highly clear images, the images with cloud cover less than 10% were selected for the study. For interpreting the shelterbelt data, we should better choose the images between May and June to distinguish shelterbelt from crop. Finally, we chose the Landsat-5 TM images of June 14, 2008 as the base image. Based on the projected 1:100000 topographic maps, whose projection is Albers Conic Equal-Area, we corrected the TM image by method of the ground control points, and the pixel error is controlled in less than half of one pixel (Zhang et al. 2006). Subsequently, we used the corrected images to interpret the shelterbelt data and land use data through man-computer interaction.

MODIS LST data

The 8-day composite MODIS LST data at 1 km spatial resolution in 2008 was acquired from http://modis.gsfc.nasa.gov. After the process of mosaic, projection transformation, clipping, removal of the abnormal value, etc. we converted the LST data into grid format. Albers Conic Equal-Area projection was used to transform the images.

Shelterbelt distribution

In accordance with the land use data, we extracted the farmland in study area, and considered this region as the shelterbelt distributional region. Subsequently, we created the grid nets with 1 km resolution and overlapped the grids with shelterbelt data. Based on the results of the previous researches, we buffered the shelterbelt data using a buffer distance of 200 m, deleted the

overlapped parts, measured the protected area in each grid, and then divided the grids into fine, normal and bad shelterbelts based on the following criteria i.e. where the protected area in a grid is below 0.3 km^2 the grid is considered bad, between 0.3 km^2 and 0.6 km^2 is normal, and above 0.6 km^2 is fine. The result is shown in Fig. 2:

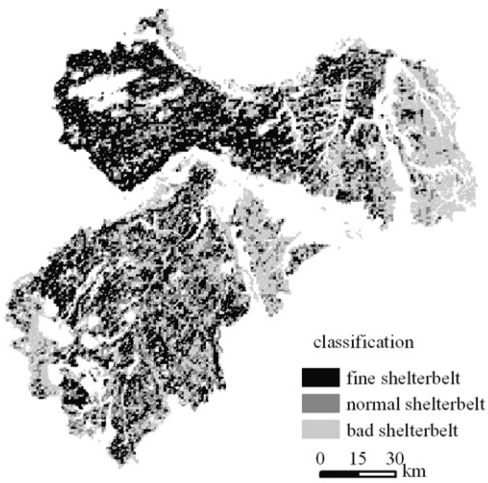

Fig. 2 The result of the shelterbelt classification in study area

Results and discussion

The change of LST

Fig. 3 represents the land surface temperature change of the different types of shelterbelt from March to October, the whole change trend synchronized with the actual conditions prevailing in this region. From the previous small scale researches, we gathered that the maximum temperature effect of the shelterbelt is few degrees centigrade; so we hardly noticed the effect clearly from Fig. 3. Hence, we subtracted the temperature in bad from the temperature in fine and normal, respectively, used the difference value to identify the differences, if the value is positive, it means the shelterbelt can play a role in increasing the temperature; otherwise, it reduced the temperature. Fig. 4 showed that the shelterbelt can increase the temperature in a whole temporal series, and the maximum temperature increment appeared between the 145th day and the 169th day, the temperature increment was not obvious between the 177th day and the 257th day, and even the temperature decrement appeared in some days. In a whole temporal series, the mean daily temperature increment was 0.57ºC in fine shelterbelt and 0.38ºC in normal shelterbelt, respectively.

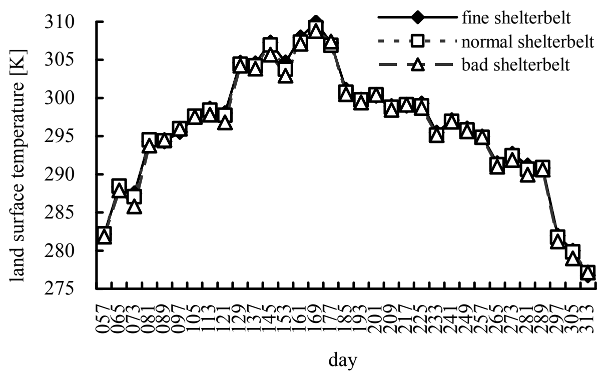

Fig. 3 The change line of LST for different shelterbelts classification

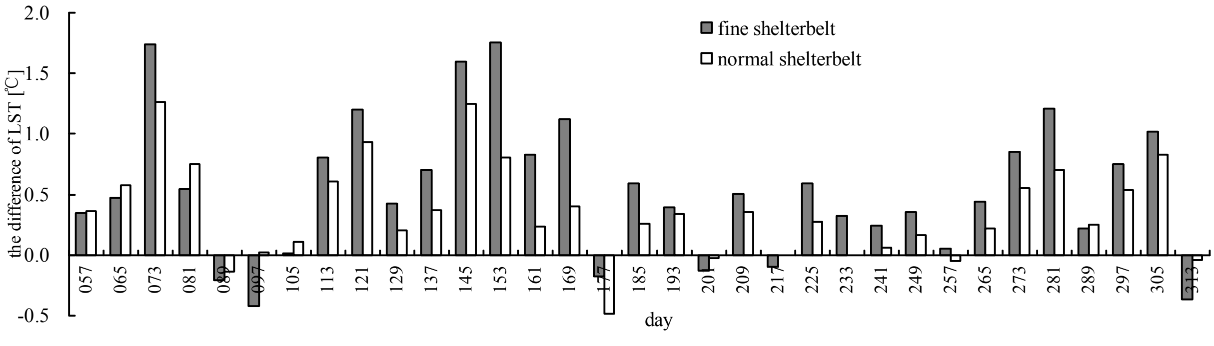

Fig. 4 The difference of the LST between fine and normal shelterbelt compared with bad shelterbelt

Analysis on the influencing factors of the protected effect

The effect of the shelterbelt on land surface temperature was relevant to the soil types and climatic conditions; therefore, we analyzed the degree of influence of these factors on the protective effect by the zoning method.

Zoning
The mean annual air temperature of the study area was between 4.1ºC and 5.5ºC; the annual precipitation ranged from 430 mm to 750 mm. The soil types are mainly black soils, chernozems, aeolian soils, albic soil*s* and meadow soils. In terms of the differences in soil types, air temperature and precipitation, we divided the study area into nine zones. The result can be seen in Fig. 5 and Table 1.

The impact of air temperature on protected effect
Firstly, we selected the zones of Ⅴ, Ⅲ and Ⅷ from Fig. 5, which

had the same soil type and precipitation but different air temperature. The soil type of these three zones is black soil, the precipitation is 500−600 mm, and the temperature is 4–4.5ºC, 4.5−5ºC and 5−5.5ºC, respectively. We subtracted temperature in bad from the temperature in fine, and then analyzed the impact of the air temperature on the protective effect. The minimum fluctuation is zone Ⅷ, and the maximum fluctuation is zone Ⅴ (Fig. 6), it meant that the shelterbelt had better effect in the lower temperature. The temperature effect of the shelterbelt from high to low was Ⅴ>Ⅲ>Ⅷ (Fig. 7), and the mean daily increment was 0.43ºC, 0.31ºC and 0.19ºC, respectively.

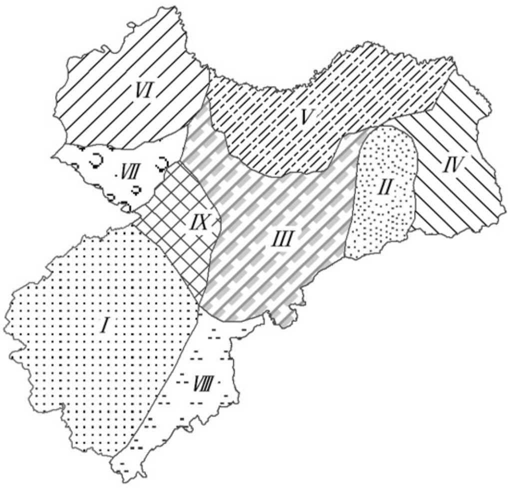

Fig. 5 The zonation of the study area

Table 1. The description of the climate and soil type for each zone

zone	annual precipitation (mm)	Mean annual air temperature (ºC)	soil type
Ⅰ	500-600	5-5.5	*chernozems*
Ⅱ	600-700	4.5-5	*black soils*
Ⅲ	500-600	4.5-5	*black soils*
Ⅳ	600-700	4-4.5	*albic soils*
Ⅴ	500-600	4-4.5	*black soils*
Ⅵ	400-500	4.5-5	*chernozems*
Ⅶ	400-500	4.5-5	*aeolian soils*
Ⅷ	500-600	5-5.5	*black soils*
Ⅸ	500-600	4.5-5	*meadow soils*

The impact of precipitation on protected effect

Secondly, we selected the zones of Ⅱ and Ⅲ from Fig. 5, which had the same soil type and air temperature but different precipitation. The soil type of these two zones is black soil, the temperature is 4.5−5ºC, and the precipitation is 600−700 mm and 500−600 mm, respectively. We subtracted temperature in bad from the temperature in fine, and then analyzed the impact of the precipitation on protective effect. From Fig. 8 we found that the temperature effect of the shelterbelt in zone Ⅲ was better than Ⅱ, and the mean daily increment was 0.31ºC and 0.22ºC, respectively. We could conclude that the protective effect reduced with the increase in precipitation.

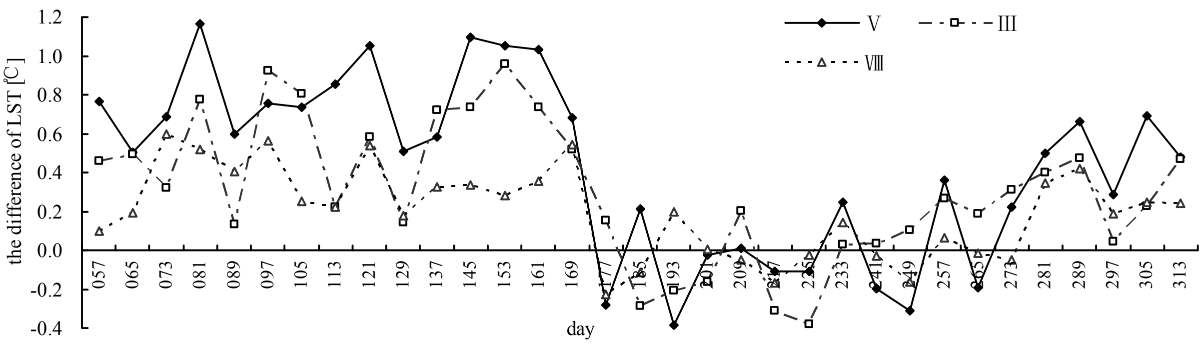

Fig. 6 The change lines of the LST values resulted from fine shelterbelt minus bad at zone Ⅴ, Ⅲ and Ⅷ

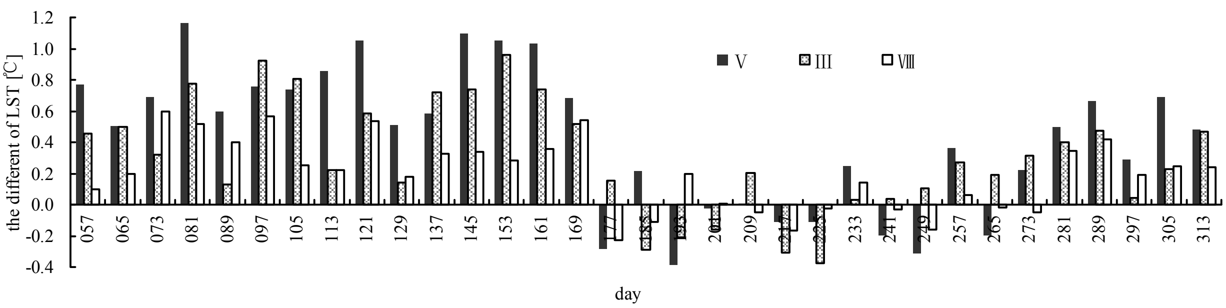

Fig. 7 The differences of the LST values resulted from fine shelterbelt minus bad at zone Ⅴ, Ⅲ and Ⅷ

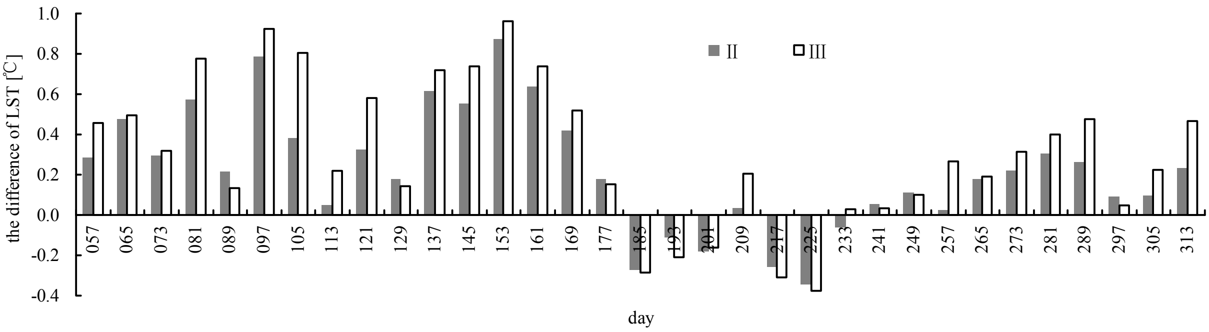

Fig. 8 The differences of the LST values resulted from fine shelterbelt minus bad at zone Ⅱ and Ⅲ

The impact of soil type on protected effect

Finally, we selected two groups of zones from Fig. 5, the first group zone comprising Ⅵ and Ⅶ had the same air temperature and precipitation but different soil types; the temperature is 4.5−5ºC, the precipitation is 400−500 mm, and the soil type of these two zones is chernozems and aeolian soil, respectively. The other group zone including Ⅰ and Ⅷ had the same air temperature and precipitation but different soil types; the temperature is 5−5.5ºC, the precipitation is 500−600 mm, and the soil type of these two zones is chernozems and black soil, respectively. We subtracted temperature in bad from the temperature in fine, and then analyzed the impact of the soil type on protective effect. From Fig. 9 we found that the difference of the protective effect between zone Ⅵ and Ⅶ was difficult to be distinguished, and the mean daily increment was 0.39ºC and 0.36ºC, respectively.

The difference of the temperature effect between zone Ⅰ and Ⅷ is not obvious (Fig. 10). Moreover, the mean daily increment is 0.15ºC and 0.19ºC, respectively. However, the differences of the temperature in these two zones were lower than the other zones; it was because these two zones had higher temperature and more precipitation, which were negative to the protective effect, so this result was consistent with the above findings.

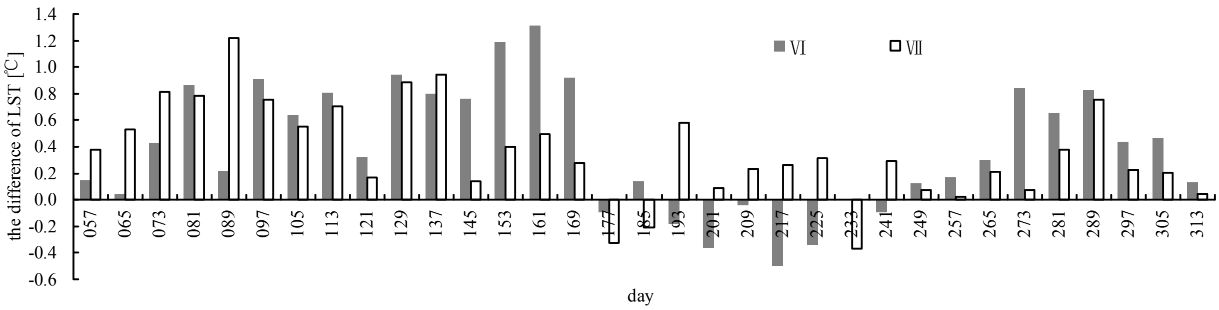

Fig. 9 The differences of the LST values resulted from fine shelterbelt minus bad at zone Ⅵ and Ⅶ

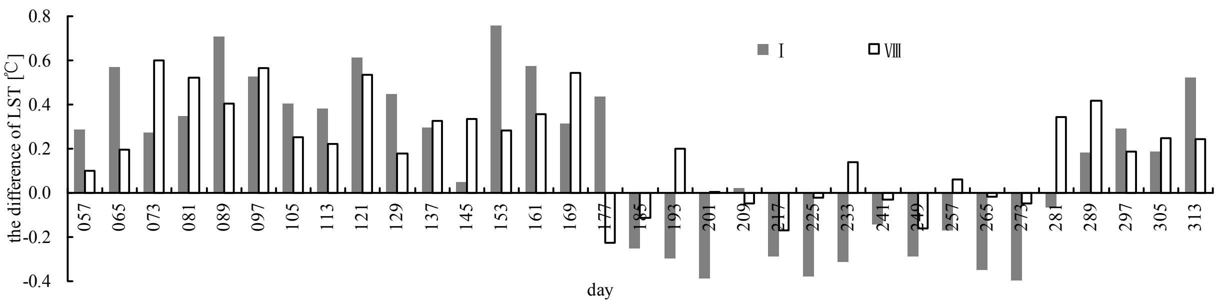

Fig. 10 The differences of the LST values resulted from fine shelterbelt minus bad at zone Ⅰ and Ⅷ

Conclusion

The present research analyzed the temperature effect of the shelterbelt at regional scale based on MODIS data. The result indicated that the temperature in protected zone is slightly higher than no protected zone. At the same time, we analyzed the impact of air temperature, precipitation and soil type on the temperature effect. In terms of climate, the relation between air temperature and precipitation and temperature effect each is negative,

i.e. the more the temperature and precipitation, the lower the effect; in terms of the soil type, the impact is not very obvious as a whole.

This paper used a new method and data source to study the temperature effect of the shelterbelt. With the development of sensor technology, the remote sensing will provide more accurate spatial, temporal and spectral resolution, which can provide more information for the shelterbelt researches, especially in regional scale.

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